

The occurrence of synanthropic triatomines in Bahia, Brazil: what changed after 40 years of the vector-control program?

Gilmar Ribeiro

Centro de Pesquisas Goncalo Moniz <https://orcid.org/0000-0003-0980-8762>

Cristiane Medeiros Moraes de Carvalho

SESAB

Renato Freitas de Araújo

SESAB

Fernanda Cardoso Lanza

Centro de Pesquisas Goncalo Moniz

Diego Lopes Paim Miranda

IGM/UFBA

Gabriel Muricy Cunha

SESAB

Orlando Marcos Farias de Sousa

Ministry of Health

Carlos G. S. dos Santos

Centro de Pesquisas Goncalo Moniz

Eduardo Oyama Lins Fonseca

Faculdade de Tecnologia SENAI CIMATEC

Roberto Fonseca dos Santos

LACEN-BA

Renato Barbosa Reis

Universidade Salvador

Rodrigo Gurgel-Gonçalves

Universidade de Brasilia

Mitermayer Galvão Reis (✉ miter@bahia.fiocruz.br)

Centro de Pesquisas Goncalo Moniz <https://orcid.org/0000-0002-3051-9060>

Research

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Abstract

Background: This study presents a descriptive analysis of the occurrence of synanthropic triatomine species in the state of Bahia, before and after the implementation of the vector control program.

Methods: Occurrence and number of collected specimens in the municipalities were analyzed in two periods: (A) 1957 to 1971, before systematic vector control actions; and (B) 2006 to 2019, after the certification of interruption of Chagas disease transmission by *Triatoma infestans*.

Results: In total, 17 species were recorded during period A and 21 during period B. *Panstrongylus megistus* was the most frequent species in period A (42%), while *Triatoma pseudomaculata* (42%) and *T. sordida* (38%) were more frequent in period B. In period A, *T. infestans* was found in 26 (9%) municipalities, and in period B it was found in 7 (2%). During period B, most triatomines (88%) were captured at the peridomestic habitats, with a predominance of *T. sordida* (85%). Species with greatest relative abundance within the household were *T. sordida* (49%), *T. brasiliensis* (27%), and *T. pseudomaculata* (15%).

Conclusions: We have observed a clear reduction in the occurrence of *P. megistus* and *T. infestans* and an increase in the relative abundance and geographical distribution of *T. sordida* and *T. pseudomaculata* after 40 years of the vector-control program. High frequency of other triatomine species in the municipalities of the state of Bahia and a great abundance of *T. sordida* in recent years, highlight the need to reinforce permanent entomological surveillance actions for Chagas disease.

Background

Triatomines are vectors of the parasite *Trypanosoma cruzi*, the etiological agent of Chagas disease. Despite being essentially wild insects, some species are capable of adapting to anthropic changes in the natural landscape, occupying the home environment [1, 2]. Many triatomines can invade houses, but few initiate colonization and domiciliation processes, which depends on characteristics of the invasive species [3, 4], of the invaded dwelling [5, 6] and the environment around the household [7].

In Brazil, some triatomine species succeeded in the process of occupying the domestic environment and expanded their occurrence beyond their original biomes [8] by active and passive dispersal [9, 10]. One of these species was *Triatoma infestans*, which occupied domiciles in 12 states of Brazil between 1975 and 1983 and it was considered the main species involved in *T. cruzi* transmission in Brazil [11, 12]. After control actions were implemented by the National Chagas Disease Control Program since 1975 and by the integrated initiatives of the Southern Cone of Latin America to eliminate *T. infestans* since 1991, a sustained reduction in domestic populations of vectors was observed [13-15]. In 2006, Brazil received from PAHO/WHO the certification of interruption of Chagas disease transmission by *T. infestans* [16].

In the state of Bahia, Pirajá da Silva performed the first research with triatomines in 1911, shortly after the *T. cruzi* description by Carlos Chagas [17]. Pirajá da Silva identified *Conorhinus megistus* triatomines

(*syn. Panstrongylus megistus*) from the city of Mata de São João, next to the city of Salvador, in the state of Bahia. He also identified triatomines in the cities of Feira de Santana, Candeias, São Francisco do Conde, and Salvador [18]. Almost 40 years after Pirajá's initial description, Chagas disease was recognized as a serious health problem in the state of Bahia, where triatomines were captured simultaneously to the record of autochthonous cases of Chagas heart disease in Salvador [19]. *Panstrongylus megistus* and *Triatoma rubrofasciata* were found naturally infected by *T. cruzi* in Salvador's historic center, associated with human cases, which motivated a chemical control campaign [20]. However, there were still foci of *P. megistus*, responsible for *T. cruzi* transmission to families in the neighborhoods of Salvador [21]. In the early 1970s, more than 600 specimens of *P. megistus* and *T. rubrofasciata* were examined in Salvador, among which 16% were infected by *T. cruzi* [22]. During this period, efforts have been made to identify triatomines in the state of Bahia, and 18 triatomine species were cataloged until the 1970s [23]. After this period, new records have been performed and new species have been described. Currently, 26 triatomine species are recognized in the state of Bahia [24-26]. Epidemiology of Chagas disease demonstrates that the state of Bahia presented higher prevalence (0.77% to 2.22%) when compared to the Northeast region of the country (0.69% to 0.88%) between 1987 and 1994 [15]. Most recent data (2008 to 2017) indicates that mortality rate from Chagas disease in the state of Bahia (3.8 to 4.8 deaths/100,000 habitants) is the highest among Northeastern states and the fourth highest among all Brazilian states; two deaths occurred in children younger than one year old, indicating the presence of acute cases [26].

Several factors can modify spatial and temporal occurrence of synanthropic triatomine species, particularly vector control through the use of insecticides, housing improvement programs, permanent training actions to combat endemic diseases, and health education for residents of the inspected households [12-16]. Comparative analyses on the dynamics of the spatial and temporal distribution of *T. cruzi* vectors are relevant for epidemiological surveillance of Chagas disease. In the present study we described the occurrence of synanthropic triatomines before (1957 to 1971) and after (2006 to 2019) the implementation of the vector-control program in the state of Bahia, which is the Brazilian state with the greatest diversity of species and the highest mortality rate from this disease in Northeastern Brazil.

Methods

The state of Bahia has 417 municipalities and it is located in Northeastern Brazil (Fig. 1). Cerrado is the main biome in Western Bahia, where there is average annual precipitation of 300 to 800mm, while in the semi-arid region, where Caatinga biome predominates, precipitation is less than 300mm, with long droughts. On the coast, annual precipitation may exceed 1500mm and its main biome is the Atlantic Forest (Fig. 1).

Descriptive analysis of the spatial and temporal distribution of synanthropic triatomines species of Bahia was performed in two periods: (A) from 1957 to 1971 and (B) 2006 to 2019. Information regarding period (A) was obtained from data published by Sherlock and Serafim [22] that presented information from the vector surveillance program of Chagas disease in the state of Bahia between 1957 and 1971, which is a

period before standardized implementation of vector surveillance programs in the country [27]. During this period, triatomine occurrence data was obtained from 206/290 (71%) municipalities that existed at the time [22]. Information regarding period (B) was obtained from State Government databases (SESAB-DIVEP-LACEN/BA) from 275/417 (66%) current municipalities after the certification of interruption of Chagas Disease transmission by *T. infestans* [28, 29].

Entomological data was obtained in three different ways: (a) Notification of triatomines (surveillance and community participation) performed by the population itself, taking suspicious insects to health agents; (b) Notification attendance (active surveillance) performed by health agents of each city, dependent on (a); and (c) Active search (active surveillance): vectors are searched in all or part of the household units of the locality, regardless of whether or not the population has made any notification. Data from literature was also included through the Google Scholar platform. Triatomine detection and taxonomic identification were carried out as established by Sherlock and Serafim [22], the National Programme for the Control of Chagas disease and the manual of triatomines of Bahia [26]. The database used in the study was organized with entomological surveillance information obtained at the state level. Each row in the spreadsheet represents a registered triatomine with the following information: species, municipality, date, GIS coordinate, the environment of sampling (intradomestic, peridomestic), and data reference. In period A, information regarding the environment of sampling was not available [22]. Geographic coordinates of the points of triatomines' occurrence were organized into spreadsheets. In the absence of specific occurrence points, we used coordinates of the city's headquarter, from the Brazilian Institute of Geography and Statistics (IBGE) [30]. Geoprocessing of the information was performed using ArcGis® Software 10.5 [31].

Results

In this study, information regarding 213,240 triatomines captured in both periods was evaluated, among which 33,543 for period A and 179,697 for period B. The highest number of species was recorded in period B (n=21) and four species already described in Bahia were not detected in the analyzed periods (Table 1). Figure 2 shows the distribution of triatomines in the municipalities in periods A and B, and the frequencies of the main species. In period A, *P. megistus* was the most frequent species (42%) while in period B, *T. sordida* and *T. pseudomaculata* were more frequent. In the last few years, *T. pseudomaculata* presented greater distribution in the state, recorded in 174/417 (42%) municipalities of Bahia, followed by *T. sordida*, recorded in 159/417 (38%) municipalities (Figure 3). *Triatoma brasiliensis* was the third species with the highest occurrence in the state (22%) (Fig. 2). There was a clear reduction in the occurrence of *P. megistus* and *T. infestans*, currently with only residual foci. *T. infestans* was last recorded in 2015 in the municipality of Novo Horizonte (Fig. 3).

Table 1. Species of synanthropic triatomines from the state of Bahia, Brazil, recorded between 1957-1971 and between 2006-2019.

Species	Period	
	A (1957-1971)	B (2006-2019)
<i>Cavernicola pilosa</i> Barber, 1937	*	*
<i>Panstrongylus lenti</i> Galvão & Palma, 1968;	*	*
<i>Panstrongylus lutzi</i> (Neiva & Pinto, 1923);	X	X
<i>Panstrongylus megistus</i> (Burmeister, 1835);	X	X
<i>Pantrongylus diasi</i> Pinto & Lent, 1946;	X	X
<i>Pantrongylus geniculatus</i> (Latreille, 1811);	X	X
<i>Parabelminus yurupucu</i> Lent & Wygodzinsky, 1979	*	*
<i>Psammolestes tertius</i> Lent & Jurburg, 1965;	X	X
<i>Rhodnius domesticus</i> Neiva & Pinto, 1923;	*	*
<i>Rhodnius nasutus</i>		X
<i>Rhodnus neglectus</i> Lent, 1954;	X	X
<i>Triatoma bahiensis</i> Sherlock & Serafim, 1967;	X	
<i>Triatoma brasiliensis</i> Neiva, 1911;	X	X
<i>Triatoma costalimai</i> Verano & Galvão, 1958;	X	X
<i>Triatoma infestans</i> (Klug, 1834);	X	X
<i>Triatoma juazeirensis</i> Costa & Felix, 2007;		X
<i>Triatoma lenti</i> Sherlock & Serafim, 1967;	X	X
<i>Triatoma melanica</i> Costa, Argolo & Felix, 2006;		X
<i>Triatoma melanocephala</i> Neiva & Pinto, 1923;	X	X
<i>Triatoma pessoai</i> Sherlock & Serafim, 1967;		X**
<i>Triatoma petrocchiae</i> Pinto & Barreto, 1925;	X	X
<i>Triatoma pseudomaculata</i> Corrêa & Espínola, 1964;		X
<i>Triatoma rubrofasciata</i> (De Geer, 1773);	X	X
<i>Triatoma sherlocki</i> Papa, Jurberg, Carcavallo, Cerqueira & Barata, 2002		X***
<i>Triatoma sordida</i> (Stål, 1859);	X	X
<i>Triatoma tibiamaculata</i> Pinto, 1926;	X	X
<i>Triatoma vitticeps</i> (Stål, 1859);		X

*Species have already been recorded in Bahia in another period; **Species today is considered synonymous with *T. lenti*; ***Captured by health agents in a wild environment.

Analyzing the geographical distribution of the main species before and after control actions, there was a reduction in the occurrence of *P. megistus* in the region of Recôncavo Baiano of the state of Bahia, where Atlantic forest areas predominated. Regarding *T. infestans*, there were also changes; it was no longer detected in some municipalities in the West (e.g. Santa Maria Vitória, Barreiras) and North (e.g. Juazeiro, Curaçá) of the state of Bahia (Fig. 3) and it started being detected in other municipalities in areas of Caatinga (e.g. Itaguaçu da Bahia, Novo Horizonte) and Atlantic forest (e.g. Tremedal and Presidente Tancredo Neves). There was a higher occurrence of *T. sordida* in Western Bahia, where Cerrado biome predominates, in South Central Bahia and some municipalities of the Recôncavo Baiano, Eastern Bahia. However, there was a greater change in the distribution of *T. pseudomaculata*, which expanded its area of occurrence in the Western municipalities (Cerrado biome) and the Central region (Caatinga biome) of the state of Bahia (Fig. 3).

When comparing total number of individuals and relative abundance of species in periods A and B, we have observed a reduction in the records of *P. megistus* (A=22,032, 62.1%; B=1,842, 1.0%) and *T. infestans* (A=1,310, 3.7%; B=763, 0.4%) and an increase in the records of *T. sordida* (A=8,314, 23.4%, B=146,901, 81.7%) and *T. pseudomaculata* (A=894, 2.5%, B=16,717, 9.3%). In period B, most triatomines (88%) were captured in the peridomestic habitats with *T. sordida* being most predominant (85%); the species with the highest relative abundance within the households were *T. sordida* (49%), *T. brasiliensis* (27%) and *T. pseudomaculata* (15%) (Table 2).

Table 2. Number of synanthropic triatomines collected in the state of Bahia, by species and environment of collection in Brazil, between 2006 and 2019.

Species	Indoors		Peridomestic		Not informed		Total	
	n	%	n	%	N	%	N	%
<i>Panstrongylus diasi</i>	6	0.04	0	0.00	0	0.00	6	0.00
<i>P. geniculatus</i>	64	0.41	43	0.03	48	1.01	155	0.09
<i>P. lutzi</i>	186	1.18	103	0.06	80	1.68	369	0.21
<i>P. megistus</i>	292	1.86	1435	0.90	115	2.41	1842	1.03
<i>Psammolestes tertius</i>	0	0.00	14	0.01	25	0.52	39	0.02
<i>Rhodnius nasutus</i>	4	0.03	0	0.00	12	0.25	16	0.01
<i>R. neglectus</i>	22	0.14	66	0.04	12	0.25	100	0.06
<i>Triatoma brasiliensis</i>	4281	27.23	6639	4.17	134	2.81	11054	6.15
<i>T. costalimai</i>	2	0.01	0	0.00	0	0.00	2	0.00
<i>T. infestans</i>	104	0.66	642	0.40	17	0.36	763	0.42
<i>T. juazeirensis</i>	141	0.90	42	0.03	42	0.88	225	0.13
<i>T. lenti</i>	19	0.12	197	0.12	10	0.21	226	0.13
<i>T. melanica</i>	0	0.00	19	0.01	0	0.00	19	0.01
<i>T. melanocephala</i>	32	0.20	4	0.00	197	4.13	233	0.13
<i>T. petrocchiae</i>	1	0.01	0	0.00	0	0.00	1	0.00
<i>T. pseudomaculata</i>	2348	14.94	13632	8.56	737	15.45	16717	9.30
<i>T. rubrofasciata</i>	4	0.03	0	0.00	2	0.04	6	0.00
<i>T. sordida</i>	7755	49.34	135865	85.34	3281	68.80	146901	81.75
<i>T. tibiamaculata</i>	456	2.90	500	0.31	29	0.61	985	0.55
<i>T. vitticeps</i>	2	0.01	8	0.01	28	0.59	38	0.02
TOTAL	15719	100%	159209	100%	4769	100%	179697	100%

Source: SESAB. **Legend:** N = Absolute number of samples; Mun. = Number of municipalities; % = percentage per column.

Discussion

The present study showed that the occurrence of synanthropic triatomines in the state of Bahia has changed after 44 years of systematized control actions were initiated in 1975. *P. megistus* was the predominant species between 1957 and 1971. After the certification of interruption of Chagas disease transmission by *T. infestans* in 2006, *T. sordida* and *T. pseudomaculata* became the most frequent species in Bahia.

Bahia was the last Brazilian state to receive PAHO's certification, probably due to specific *T. infestans* identification errors and appearance of new records of this species in the study area [32]. Nine species biogeographically unlikely to be found within households in Bahia [25, 33] were recorded by the surveillance service: *Belminus laportei*, *Eratyrus mucronatus*, *Microtriatoma trinidadensis*, *Panstrongylus tupyambai*, *P. lignarius*, *Rhodnius prolixus*, *Triatoma maculata*, *T. circummaculata*, and *T. rubrovaria*. To reduce taxonomic identification errors, a guide was developed [33] and, more recently, a guidance manual to the surveillance service of triatomines in Bahia, with identification keys, diagnosis, and distribution of vector species [26].

In general, there was a reduction in the occurrence of the main *T. cruzi* vector species in the 1960s and 1970s. In period A, *T. infestans* were found in 9% of the municipalities and represented 3.7% of collected triatomines while *P. megistus* was found in 42% of the municipalities, with a relative abundance of 62% of collected triatomines [23]. In period B, *T. infestans* were only identified in seven municipalities among residual colonies [34, 35], representing 0.4% of collected triatomines. The occurrence of *P. megistus* has greatly reduced in the state of Bahia, especially in the region of Recôncavo Baiano and the metropolitan region of Salvador. Its occurrence has also reduced in other Brazilian states [11, 36-38]. Three hypotheses could explain this reduction in the metropolitan region of Salvador: (a) Chemical control was successfully performed over four decades resulting in the elimination of domestic populations of *P. megistus*; (b) Intense urbanization on these municipalities resulted in deforestation and fragmentation of Atlantic forest areas, which is the natural habitat of the species [23]; (c) Housing improvement, with progressive depletion of adobe houses [39,40], a favorable environment for *P. megistus* colonization. Elimination of *T. infestans* in several municipalities in Western and Central Bahia can be explained by the *T. infestans* elimination plan, which was intensified in 2004 with actions of household spraying of insecticides, followed by research and capture of triatomines, completed in about 500,000 homes [26]. However, residual colonies of the species were detected in other municipalities [28, 29] which requires constant monitoring to definitively eliminate *T. infestans* from the state of Bahia. Thus, we suggest that surveillance and triatomine control activities should be prioritized in these regions.

In addition to the chemical control performed in Bahia since 1975, intensified in 1991, which aimed to eliminate *T. infestans* [11, 15], other social actions were implemented by the Federal Government such as the growth acceleration program intended to improve housing quality, with the replacement of mud-houses by brick-houses. It may also have influenced the reduction of household colonization by *T. infestans* and by other household species [39, 40].

Despite the success of actions to control triatomines, several other native species were recorded in a larger number of municipalities. They were captured in the household and frequently colonized peridomestic structures. Among them, some were infected and many were being fed by domestic animals and even human blood [41]. In period A, *T. sordida* was recorded in 26% of the municipalities, representing 23% of collected triatomines, while *T. pseudomaculata* was recorded in 14% of the municipalities with a relative abundance of 2.5% of collected triatomines [23]. In period B, *T. sordida* was recorded in 38% of municipalities, representing about 82% of triatomines. *T. sordida* has been the most common species

among different regions of the state of Bahia. In a similar situation, *T. pseudomaculata* was the species that were identified in the largest number of state municipalities in period B (42%). The systematic vector-control actions had a very low impact on the spatial distribution of *T. sordida* and *T. pseudomaculata* in the state of Bahia. There was a higher occurrence of *T. sordida* in Western and South Central Bahia, where there are areas of Cerrado, which is the origin biome of this species' natural populations [1,2,25]. The highest occurrence of *T. pseudomaculata* in Western and Central Bahia is in accordance with the occurrence predictions of the species based on environmental variables [42]. The number of specimens of *T. sordida* and *T. pseudomaculata* together exceeded 90% of all triatomines collected in the state between 2006 and 2019.

It was observed a higher occurrence of *T. brasiliensis* and records of similar species in Bahia, expanding observations of Ribeiro-Jr *et al.* [41]. Before systematized control actions, *T. brasiliensis* was registered in 6% of the municipalities of the state of Bahia, and between 2006 and 2019 at least 93 municipalities (22%) registered this species. In the last few years, other species of the *T. brasiliensis* complex have been described in the state of Bahia, such as *T. juazeirensis*, *T. melanica*, *T. sherlocki*, and *T. petrocchiae* [43]. Among these species, we highlight *T. juazeirensis* since it was collected predominantly inside the household units. Other species such as *T. tibiamaculata*, *P. geniculatus*, *T. melanocephala*, and *P. lutzi* were detected in the households, mainly the adults.

There was an important difference in the occurrence of *T. tibiamaculata* between the two periods. In period A, this species was recorded in about 1% of the municipalities with a relative abundance of 0.01% [23] and in period B it was recorded in 4% of the municipalities with a relative abundance of 0.55%. In recent decades, *T. tibiamaculata*, which is naturally found in the nests of marsupials, rodents, and epiphytes in forests [1,22], has been recorded in peridomestic palms and inside houses, offering risk of *T. cruzi* transmission in the city of Salvador [44].

The present study has some limitations. The use of reference databases does not allow a broad analysis of the data; it was not possible to obtain data on the occurrence of triatomines within habitats (intra and peridomestic) in period A (1957-1971). Moreover, not all 417 municipalities collect data regularly in period B; the health surveillance service classifies municipalities in high, medium and low risk of transmission, emphasizing that there is no obligation to conduct regular entomological research in low-risk municipalities, based on the classification presented by Brazil's Ministry of Health [26]. Future studies reassessing risk classification at a municipal level are urgent for the redefinition of areas and risk of transmission. Further studies should analyze the situation of these silent areas to explain whether the absence of triatomines is due to the functioning of the service or biogeographic issues related to triatomines. In period A, species of *T. brasiliensis* complex were considered as one species - *stricto sensu* - while in period B *T. brasiliensis* complex was classified into six species: *T. brasiliensis*, *T. juazeirensis*, *T. melanica*, *T. lenti*, *T. bahiensis*, and *T. petrocchiae* [43].

This study concludes that there was a change in the occurrence of triatomines between the analyzed periods, 40 years after the implementation of the vector-control program in the state of Bahia. We

observed a reduction of the occurrence of *P. megistus* and *T. infestans* and an increase of relative abundance and geographic distribution of *T. sordida* and *T. pseudomaculata*. Changes in the occurrence of *T. cruzi* main vectors between the studied periods indicate the need for continuity of entomological surveillance actions of Chagas disease. Also, it highlights the importance of promoting and the strengthening of surveillance, community participation, and health education actions of Chagas disease, in addition to new strategies to control triatomines.

Abbreviations

SESAB: Epidemiologic Surveillance team of Bahia State Health Service; GPS: Global Position System; GIS: Geographic Information System; PAHO/WHO: Pan American Health Organization; DIVEP – Epidemiological Surveillance Office; LACEN/BA: Central Public Health Laboratory of Bahia.

Declarations

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Ethics approval and consent to participate

The adopted procedures were in accordance with the ethical standards of the Research Ethics Committee of the Gonçalo Moniz Institute (FIOCRUZ, Bahia, Brazil) nº 2.552.284 and with the Helsinki Declaration of 1964, revised in 1975, 1983, 1989, 1996, and 2000. The consent form was waived because the analysis was based on a state surveillance service of Bahia – Brazil. However, no personal identification data were used to ensure the complete anonymity of participants. The research did not cause any physical, psychic, moral, intellectual, social, cultural, or religious risk to the residents and animals of studied areas. Also, our study did not involve endangered or protected species.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that there are no conflicts of interest associated with this study.

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Author's Contribution

GR-Jr, RG-G, and MGR conceived the study. MGR raised funds and administered the project. GR-Jr, RG-G, MGR, contributed to the design of trial methods. CMMC, RFA, FCL, DLPM, GMC, OMFS, CGSS, EOLF, RFS and RBR performed research. GR-Jr and MGR supervised students involved in field and laboratory research. CMMC, RFA, GMC, OMFS, CGSS, RFS obtain the databases, GR-Jr curated the dataset and analyzed the data. GR-Jr, RG-G and MGR drafted the first version of the manuscript. All authors contributed to the interpretation of results, read and commented on manuscript drafts, and approved the final version.

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Figures

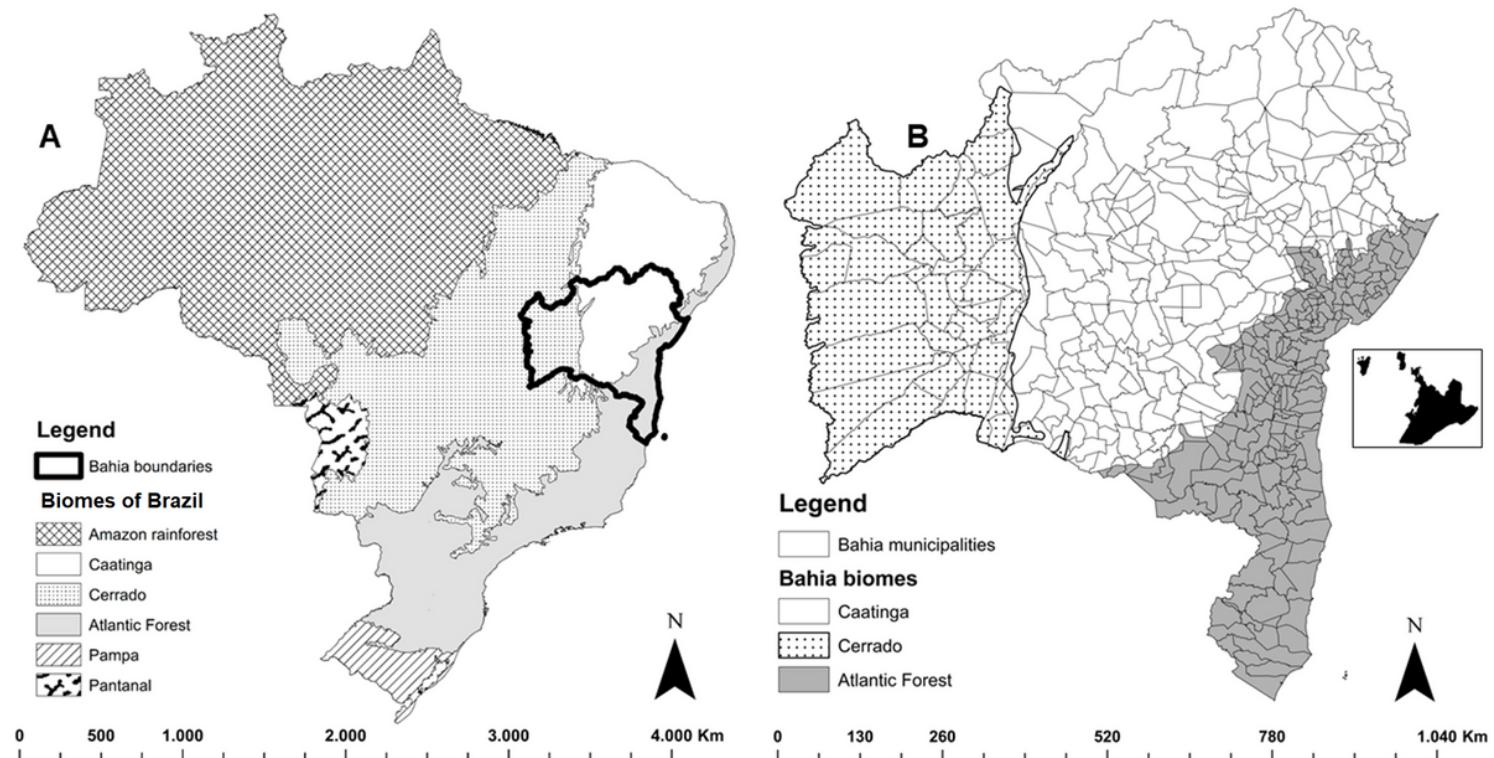


Figure 1

Study area. Biomes of Brazil and geolocation of Bahia (a). Municipalities of Bahia (b); inset shows the City of Salvador in detail).

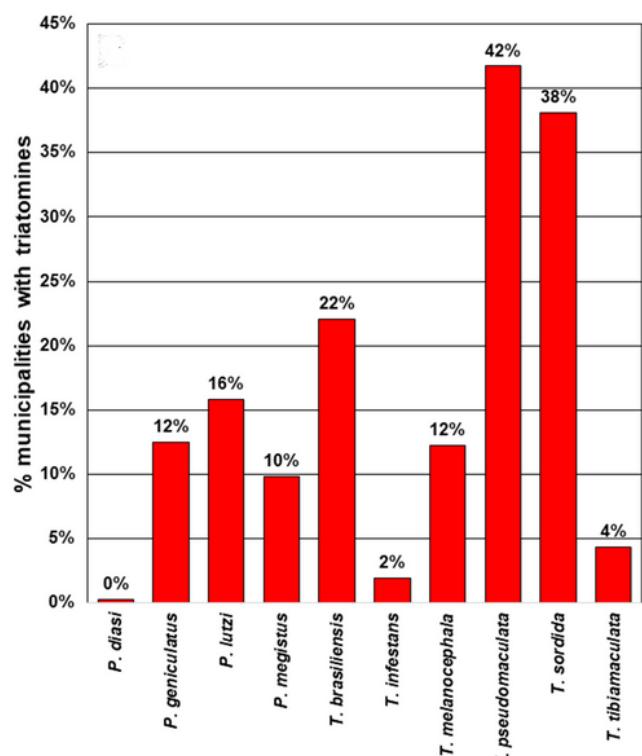
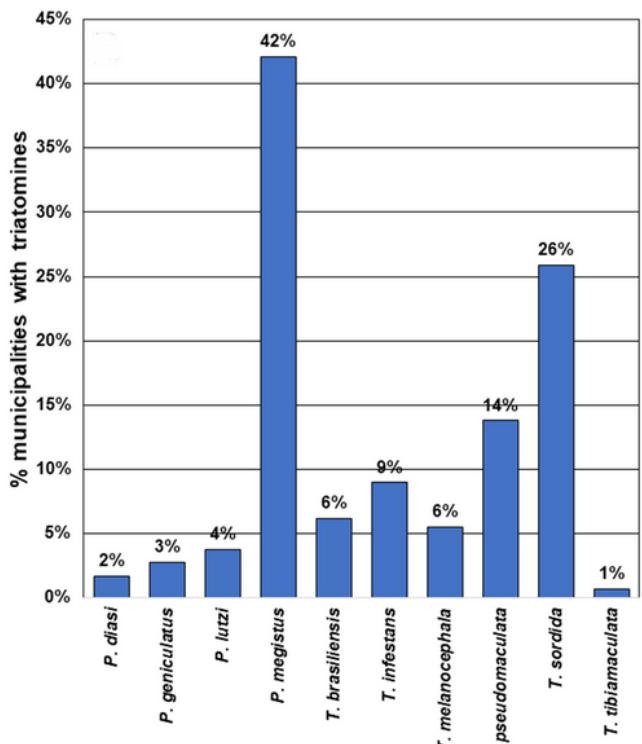
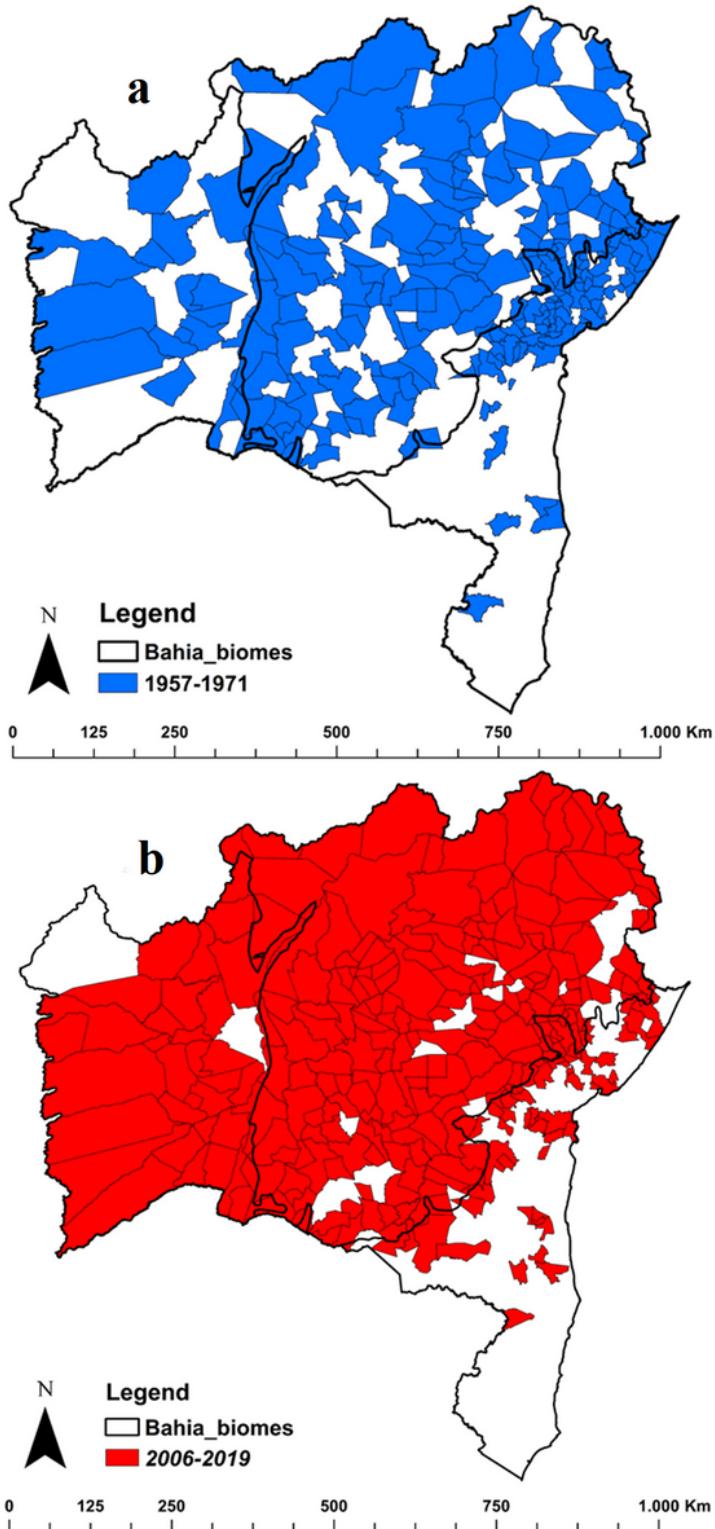


Figure 2

Municipalities with the occurrence of triatomines in the state of Bahia in periods A (1957-1971) and B (2006-2019) and percentage of municipalities with records of the main species of collected synanthropic triatomines.

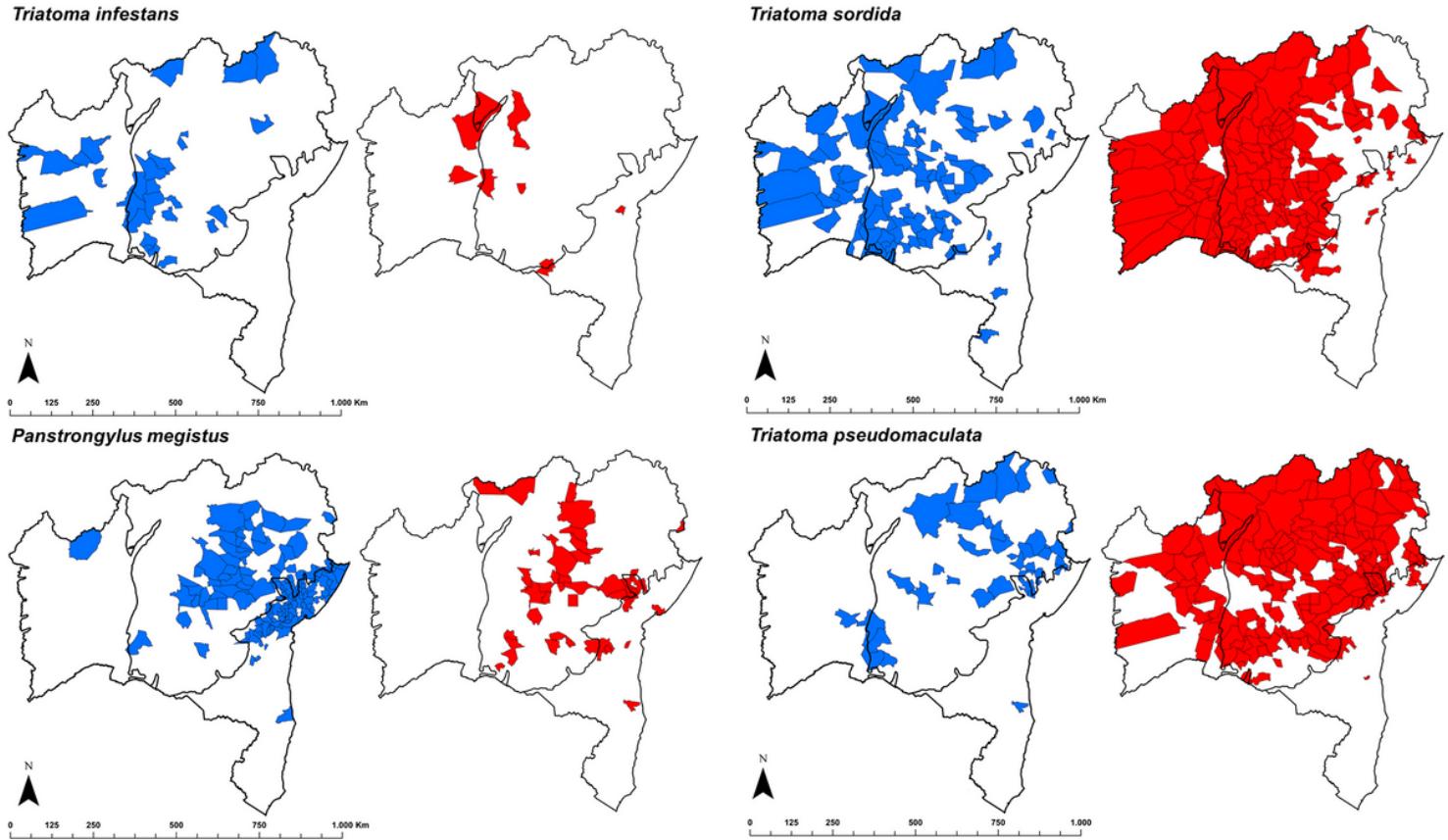


Figure 3

Geographic distribution of *Panstrongylus megistus*, *Triatoma infestans*, *T. pseudomaculata* and *T. sordida* in the municipalities of the state of Bahia in periods A – in blue (1957-1971) and B – in red (2006-2019).

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